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# Visualisation of Geographic Data in Virtual Environments

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## Summary

Virtual Environments (VE) are characterised as a computer-based generation of scenes of abstract or realistic environments, which can be perceived consistently. The use of VE is very promising in several areas, especially when visualisation of complex data in a realistic and clearly understandable way is needed. For military applications VE technology has potential in the area of research and development, training, mission support and mission rehearsal.

A further application is use in Command & Control (C<sup>2</sup>)-systems due to upcoming demands in this area.

In future battlespace scenarios huge amounts of highly dynamic information will be available due to the technical development of sensor, communication and information systems. Therefore advanced techniques for supporting the military commander and displaying complex tactical situation data in a clearly understandable way have to be developed and evaluated.

In this connection a concept for pre-processing and visualising incoming tactical data and three-dimensional geographical data has been developed. This "Electronic Sandtable (ELSA)", as described in this paper, uses VE technology. The ELSA facilitates a plastic stereoscopic visualisation of three-dimensional data. It has been designed to simulate a sandtable as commonly used by the Armed Forces for tactical education and training.

Therefore the visualisation of digital geographic data (elevation (DTED) and feature (DFAD) data) is necessary.

This paper focuses on the stereoscopic visualisation of geographic data. Therefore different stereoscopic projection models are described and compared to each other. For the Electronic Sandtable a model with a window projection was chosen and implemented. The baseline concept and first results of this implementation are referred to in this paper.

## 1. Introduction

Huge amounts of highly dynamic information will be available in future battlespace scenarios because of the technical development of sensor, communication and information systems. Broad data acquisition, transfer, and presentation will enable the military commander to get a variety of diverse information about the battlefield scenario. The accomplished information dominance is

more and more considered to be essential for a battlespace dominance.

But the massive quantity of information is also hazardous. Especially in time-critical situations when tactical decision making under stress is required, relevant information may be overseen and a wrong mental model of the tactical situation might be gained.

That overload is likely to be reduced by using new technologies for data pre-processing and data presentation. Because data presentation is of critical importance in the whole process of decision making, ergonomic research is required to analyse the whole process of data presentation, considering new displays and interaction devices.

Especially using Virtual Environment (VE)-technology is promising. It was found to have high potential in presenting and interacting with complex amounts of data. Therefore VE will increase the clearness and intelligibility of a complex tactical situation. The situation scenario is not perceived as a complex of abstract information but as a pseudo-realistic model landscape. This is intensified by an intuitive, easy to learn interaction with the included objects.

## 2. Command and Control (C<sup>2</sup>) Systems

Command and Control (C<sup>2</sup>) Systems have been designed to support the military staff in co-ordinating defensive, peace keeping and enforcing missions, exercises, humanitarian aid and ministerial expertise. For this reason diverse sensor information data and information data of knowledge databanks are joined in these systems. A part of C<sup>2</sup> is the output and presentation of tactical information. It has large influence on the general decision making process, because the commander's mental model of the battlespace situation is based upon the information perceived.

The SHOR-model (Stimulus, Hypothesis, Option, Response) of decision making introduced by Wohl (1981) proves this. It describes the process of decision making from data gathering to executing responses. The available and pre-processed information of a C<sup>2</sup>-System is displayed by the Tactical Situation Display (TSD).

### 2.1 Tactical Situation Displays (TSD) today

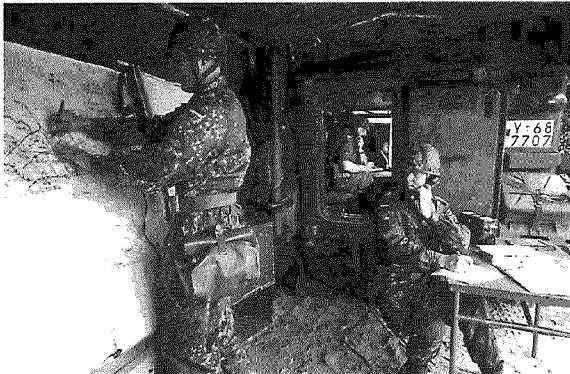
The basic function of TSD is to display the current situation of own and reconnoitred enemy troops and

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facilities in the operation area to the commander of a military unit.

Moreover the TSD is used for tactical planning of intended future operations. Quantity and quality of situation data are essential for an adequate operation planning (Grandt et al., 1997).

Today's conventional TSDs might not be able to meet the demands of future battlespace scenarios and have to be extended by new, innovative technology. The strike forces today uses two basically different types of TSDs. The first one, shown in Figure 1, is a *command post in the field*. The TSD used here works by means of paper & pencil. Actual information is transmitted by radio or field telephone and drawn into a map.



**Figure 1:** TSD at command posts “in the field”

It is obvious that in time-critical processes with large amounts of rapid changing information this leads to an overload of the operators. Moreover, the display may not show valid or actual information and causes errors in decision-making. However, it brings along the advantage that the commander is in the field: He gains high situational awareness, experiences the terrain, cover, weather, etc. and knows “what is really going on” at that place.

On the other hand there are *TSDs at operation centres*. Tactical situation data is pre-processed and computers are used to visualise the results.

The advantages of these computer-based TSDs are: Actuality of data, provided that the communication infrastructure is fast enough; and different views of levels of data aggregation and possibilities to include additional battlespace information.

But the flood of information may lead to an information overload and data representation is still limited to two dimensions and techniques of interaction with data have to be learnt.

The approach of using VE as TSD first expands the two-dimensional visualisation to three dimensions. This means that height information can easily be perceived. Additional elevation aids, like elevation profiles or colour texturing, can be skipped and replaced by others (e.g. reconnaissance photos, weather data, etc.).

The more important thing is that general interaction with data is simplified and happens more intuitively. This facilitates an experience of the tactical situation and the

generation of a correct mental model. In an ideal VE-system the computer is not realised as an active entity, but becomes an invisible assistant which knows about user intentions and supports him (Alexander et al., 1997). Therefore operator workload is supposed to be reduced and situational awareness to be increased.

## 2.2 Application of VE-Technology in C<sup>2</sup>-Systems

The amount of studies and applications in the area of VE and VE-technology has increased rapidly recently. But whereas VE is close to become applicable in research and development and for single training applications, studies considering the specific use of VE in C<sup>2</sup> have just begun. Therefore knowledge in this area is limited and a lot of projects are in a conceptual phase.

Most research studies and projects in this area have been started in the past two years. Because of ongoing development in this area this is only a brief overview. Detailed information is given in Alexander et al. (1999). Generally speaking, the approaches can be divided into two groups. The first group consists of concepts and long-term programs including VE-components. This is a top-down approach, which is at high political level and typically application-oriented. The second group is characterised by specific VE-projects and laboratories. Consequently it follows a bottom-up approach and is presentation- and technology-oriented. Fortunately, there are links between both so that they meet and synergetic effects exist.

The Swedish *ROLF (Mobile Joint Command and Control System 2010)* is a long-term program. Its goal is to determine new possibilities for military commanders of using VE-Technology in mobile command posts. ROLF describes requirements for situational awareness, decision-making and support, work methodology and organisation of military crew and staff. The main idea is to use modern methods and technology to help a group of operators in difficult situations with complex, time-critical decision making. ROLF includes the *Aquarium* as TSD, which is a semi-immersive VE-system. The TSD is used to visualise positions of own and enemy troops, positions of important institutions, terrain and weather data in different views. Data pre-processing is used to select the data displayed and ensures that only important information is visible (Sundin, 1996).

Especially the realisation that in future battle scenarios all actions of the military commander will be in an unclear, vague environment and the importance of an information dominance led to the development of the *Command Post of the Future Program (CPoF)* of DARPA (1998). The program's goal is to accelerate the decision making process with ongoing reduction of the staff. Therefore new technology is needed to make maximum use of the whole human perceptory system in order to transmit maximum amount of information. This includes an interactive, three-dimensional visualisation, three-dimensional interaction with computer-generated objects, presentation of inaccuracy and probability, integration of dynamic factors, three-dimensional sym-

bolic, integration of natural language processing and integration of knowledge-based systems.

The second, more technology-oriented group of approaches is larger. Institutions and laboratories working in this area use different VE-technology. The technology is often reconfigured to be used in different research projects and experiments.

The *US Battle Command Battle Lab (BCBL)* performs conceptional studies as well as experimental analysis in a VR-laboratory. One goal is to develop a technology for multi-media, scene-based application in education and training for organisation and staff functions. This system shall be connected to the Internet to increase the range of application (Heredia, 1999).

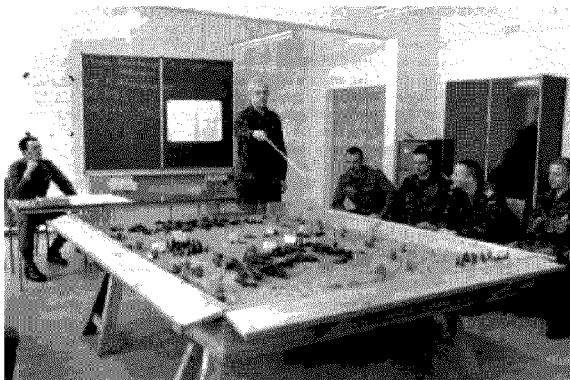
At the *US Naval Research Laboratory (NRL)* an advanced battle planing and management system has been developed. The system works with a semi-immersive display and enables multi-modal interaction. It was found to be very suitable for virtual-prototyping, interactive mission planing and increasing situational awareness (NRL, 1997).

Similar approaches, like *Mirage* of the Army Research Lab (ARL) (IST, 1997), the *Visualisation Architecture Technology (VAT)* of the Crewstation Technology Laboratory (CTS) (Achille, 1998) or the *Electronic Sand Table* of MITRE Corp. (MITRE, 1998) also use a semi-immersive VE-technology, as described further on.

Other approaches use full immersive VE or desktop-VE respectively (Dockery & Hill, 1996; Morgenthaler et al, 1998).

### 2.3 The Idea of an Electronic Sandtable

The Electronic Sandtable at FGAN/FKIE has been developed as an advanced display for tactical information in mission planing, control and rehearsal. The concept is based on the sandtable metaphor. The military sandtable, as shown in Figure 2, consists of a sandy model landscape with simplified objects representing woods, buildings, points of interest or military units. It is broadly used in military education and training.



**Figure 2:** Sandtable in military education

But the traditional sandtable is static; all changes of deployment have to be done manually. Each change of region is very time-consuming and has also to be done

manually. Moreover the accuracy for representing real geographic data is poor.

It is intended to model the sandtable by means of a VE-system. This way the system becomes capable of presenting dynamics, enabling real-time interaction and changes of the point-of-view while benefits of the real sandtable remain.

For this purpose geographic data and tactic data have to be visualised stereoscopically. It is intended to create a model landscape, in which dynamic battle scenario is included.

Furthermore additional functionality can be added, e.g. visibility, range of weapon systems, etc. The implementation of this idea will be described in detail in chapter 5.

### 3. Virtual Environments (VE)

The basic idea of generating and using a computer-generated artificial reality was mentioned first in science fiction literature at the middle of the 20<sup>th</sup> century. Due to rapid development of computer technology in the second half of the century, a partly realisation of this idea became possible. Nowadays these VE-Systems are commercially available and starting to be used for a broad range of applications (Alexander et al, 1999).

According to Bullinger et al (1997), Virtual Environments (VE) describe the computer-based generation of an intuitively perceivable and experiential scene of a natural or an abstract environment. It is characterised by capacities for multi-modal, three-dimensional modelling and simulation of objects and situations. A further characteristic is the close interaction of the human operator with the system.

In this connection, Virtual Reality (VR) has been defined by NATO HFM-021 (nn.) as:

"... the experience of being in a synthetic environment and the perceiving and interacting through sensors and effectors, actively and passively, with it and the objects in it, as if they were real. Virtual Reality technology allows the user to perceive and experience sensory contact and interact dynamically with such contact in any or all modalities."

This definition of VR, which is often used as a synonym to VE, overlaps with VE. But whereas VE is application oriented, VR describes, strictly speaking, a total model of the reality, including all manifold facets of it. As this is not possible today and may not be possible in future, the further article will use the term VE.

VE-systems are on their way of becoming to be used for different applications. The main applications have found to be research and development, training, telemanipulation and teleoperations, mission support, and mission rehearsals. Further information about military applications is given in Alexander et al. (1999).

### 4. Geographic Data

Geography is the science of analysis of the surface of the earth and the earth-human ecosystem. The historic roots reach back to the antique world when geography was

used for the description of land, coasts and harbours. Still the description of the surface of the earth, called cartography, is one of the largest domains of geography. However, today geography is not limited to physics (geomorphology, climate, hydrographics, soil science, and geography of vegetation and animal), but includes political, social, economic and cultural aspects as well.

The structure of geographic databanks depends on the kind of application the data is intended for. Usually offices for land register and military offices are the main principals and users.

Data for military cartography has to be as exact, complete and actual as possible. This means a complete collection of data about all kinds of objects and the exact registration of their geographic co-ordinates is main criteria for structure of the referring databank.

The *geographic data* available is divided into (Helmuth, 1996):

- *Raster data*, which describes a subset of pixel data, like scanned paper maps of different scales. Assignment to other geographic data requires geo-referencing by means of the determined values for the map's corners.
- *Picture data*, which comprises geo-referenced or non-referenced aerial or satellite photos. Equalising reference points or procedures of aerial triangulation do geo-referencing.
- *Vector data*, which includes pre-processed data of surfaces (e.g. woods, lakes), lines (e.g. streets, rivers) or points (e.g. power poles, points of interests, bridges, towers) and the positions of their bases and attributes. Vector data is usually two-dimensional feature data and has to be merged with elevation data from other sources. For visualisation vector data is linked to detail objects.
- *Matrix data*, which describes terrain data structured and saved in matrix format. Usually, terrain data is organised like this.

All categories differ from each other in quality, resolution and actuality. Generally, data is available in scales between 1:25.000 and 1:250.000. The most common data-format is summarised in Figure 3.

Data Type	Name	Resolution / Scale (dep. on region)
Raster	MRG	1:50.000 - 1:2.000.000
	PCMAP	1:50.000 - 1:2.000.000
	ADRG	1:50.000 - 1:1.000.000
Picture	aerial photos	1:32.000 & 1:70.000
	satellite photos	10 m X 10 m
	SPOT satellite photos	30 m X 30 m
Vector	Landsat-TM	
	DLM	1:25.00 - 1:1.000.000
	DCW	1:1.000.000 & 1:2.000.000
	DFAD	1:250.000
	VMAP	1:50.000 - 1:250.000
Matrix	U-VKN	1:50.000
	DHM/M745	30 m X 30 m
	DTED	90 m X 90 m
	DGMA	90 m X 90 m

**Figure 3:** Different Formats of Geographic Data (Helmuth, 1996)

With growing demand on realistic education and training and ongoing technical development of displays new requirements for geographic data are emerged. In the future the main needs will be higher resolution and realistic texturing.

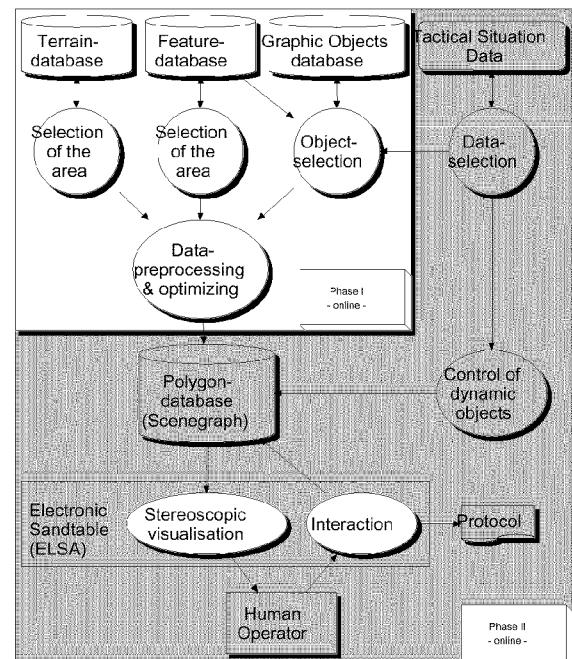
However, it cannot be taken as granted that all data required is available in the format, resolution and quality needed for the application. For this reason, an extension of one databank by different other databanks has to be done. This may lead to inaccuracies and inconsistency making further data processing necessary.

## 5. Electronic Sandtable (ELSA)

The Electronic Sandtable has been implemented as a testbed at the Research Institute for Communication, Information Processing and Ergonomics (FKIE). The structure and implementation of the semi-immersive VE-system is described in this chapter.

### 5.1 Baseline Structure

Because of the large size of geographic databanks and the need for real-time interaction, the underlying structure has been arranged in two stages (Alexander et al., 1997). A draft of this subdivision of the structure is given in Figure 4.



**Figure 4:** Structure of the Electronic Sandtable

*The first stage is executed offline.* In this stage the scene graph is determined. The scene graph is a hierarchically ordered databank of all polygons included in the visible scene.

In a semi-automatic process data and objects are selected, integrated and re-ordered with respect to maximum rendering performance. This re-ordered polygon-databank is called the scene graph. Afterwards

the scene graph stays constant without any changes of its structure.

*In the second stage additional data is constantly added and the scene graph is visualised online.* The additional data, i.e. tactical situation data and data from external data sources, is linked to objects of the scene graph. Additional input of external data using different protocols (DIS, HLA) shall also become possible in future. The incoming data controls position and status of military units. Additional data like actual situation videos or information of knowledge databanks can, also be included.

After that the rendering subsystem selects the visible subset of the scene graph. Out of this two separate projections are calculated and written into two-frame buffer. Then both frame buffers are visualised alternately on a horizontal plane.

The human operator interacts with the scene by means of different interaction devices. The inputs serve as commands, which affect the objects of the scene graph. They are logged for later analysis.

The operator is able to select different visible areas for navigation. The borders of the area serve as one input variable of the rendering subsystem. Additionally each of the operator's movements is tracked by a head-tracker. The position output of the tracker is another input variable of the rendering subsystem for new projection calculation.

## 5.2 Data Processing and Visualisation

For visualisation the geographic data has to be transferred into the scene graph to be visualised. The process is executed offline and done semi-automatically. It is divided into *data selection, pre-processing and optimising phase*.

*In the first step an area of interest is selected* and the relating terrain (DTED) and feature (DFAD) data is extracted. Additionally, links between features and geometric objects are defined. Afterwards the selected data is saved in a temporary buffer, which has to be pre-processed, and optimised for visualisation.

Geometric objects include the geometric description of the object (e.g. tanks, aeroplane) and additional information (e.g. unit status, damage reports, etc.). At the stage of real-time visualisation they are shown at the position given either by the geographic data or the tactical situation data.

The following steps of pre-processing and optimising are necessary because terrain and feature data are generated from geographic databanks. These databanks were designed with regard to different requirements, which makes them unsuitable for a real-time, realistic visualisation.

*Pre-processing* takes into account that consistency and integrity are highly important criteria for databanks. If datasets of more than one databank are merged, contradicting data might emerge and cause errors. Those errors are based on errors or inaccuracies in the original databanks, different data resolution or different actuality of data acquisition.

As soon as consistency and integrity is proved, the process of merging terrain and feature data starts. Geometric objects are appended and, if necessary, adjusted to ground level.

Finally the triangulation process starts and determines polygons for visualisation.

*For real-time visualisation an optimising process* has to be performed to keep the amount of rendered polygons minimal. Therefore the databank system transfers only information about the visual subset. Non-visible parts outside the field of view are clipped.

For further reduction the databank is re-organised and the scene graph is tiled. In the visualisation process the distance to the point of view sets the level of complexity for each tile.

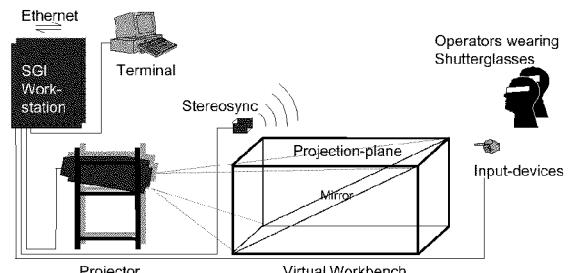
Different levels of complexity called levels of detail (LOD) are another technique to reduce polygons. LOD means more than one representation of different levels of complexity (different amount of polygons) for the same subset. This means, if a subset gets closer to the point of view, a higher LOD with more polygons is visualised.

Using these techniques, data is re-organised with regard to visualisation issues. The output of this process is the scene graph, which can be visualised in real-time on the display.

## 5.3 Concept of Semi-immersive Display Technology

The display technology used for three-dimensional visualisation is a semi-immersive virtual workbench. Krüger & Fröhlich (1992) have originally developed this concept. The baseline concept is shown in Figure 5. Today it is used for various applications.

A projector projects two computer-generated, time-alternated pictures onto a mirror. The mirror reflects them to a horizontal focussing screen. By using shutter glasses, i.e. LCD-glasses shading each side alternately synchronous to the projection, the operators perceive two separate pictures for the right and the left eye. The synchronisation works by an emitter sending infrared signals synchronously to the picture projected.



**Figure 5:** Principle of a Semi-Immersive Virtual Workbench

Finally, both pictures perceived are fused by the cerebrum to a single, three-dimensional model.

## 6. Stereoscopic Visualisation

The design of the user interface of VE-systems has been found to be one of the main criteria of quality for its application. The Electronic Sandtable (ELSA) serves as

the interface between the real environment on the one hand and the virtual scene on the other hand. Moreover it uses a different metaphor than the desktop-metaphor used in various computer applications. Therefore new interaction techniques and procedures have to be developed, analysed and optimised according to a high performance of the human-computer-system (Alexander, 1999).

A realistic, three-dimensional visualisation of terrain data has to consider the physiological procedures of visual depth perceiving. These procedures have been studied extensively, and several different hypothesis for depth perceiving exist.

Each hypothesis postulates the existence of depth cues. The classic depth cues will be summarised later in this chapter. Of those especially the stereoscopic disparity and parallax are of critical importance for the application of the Electronic Sandtable.

A computer-based visualisation has to take into account different depth cues. For stereoscopic visualisation different viewing models exist. The common models will be presented in this chapter as well.

### 6.1 Process of Visual Perception

The physiological visual system consists of the eye as sense organ for stimulus acquisition, the optic nerve for stimulus transfer and the optic centre of the cerebrum for stimulus processing.

According to Schmidt & Thews (1995) the human eye can be divided into two subsystems:

- Subsystem 1 performs the refraction of incoming light. Its main components are Iris (control of incoming light intensity), lens (refraction), vitreous body (stability) and diverse muscles (adjustment).
- Subsystem 2, jointly with the central nervous system, transfers the light to stimulus signals of nerve cells. It consists of the retina with its two different light receptors.

The stimuli are transferred via the optic nerve to the optic centres of the cerebrum. Here the optic sensing and recognition takes place.

Visual perception is generally based on three stages of perception (Kelle, 1994):

The first stage is an egocentric perception of the own person. This allows a separation of objects of the own body and other objects, making possible to determine the own position with regard to other objects and an *absolute depth perception*.

The next step is a comparison of the objects in the environment, allowing a *relative depth perception*.

Finally memory, experience and internal processing mechanism lead to *depth cues* being fundamental for spatial perception.

### 6.2 Depth Cues

Depth cues are visual system cues, which enable perceiving of spatial dependencies (Hodges, 1992; Schmidt & Thews, 1995). They can be divided into monocular and binocular cues.

Monocular cues are valid for perception with one eye only.

The main monocular cues are:

- *perspective*: The projection of three-dimensional environment onto a two-dimensional display surface has large influence on the subjective depth perception. Most common projection is the linear projection characterised by parallel lines meeting at a single vanishing point.
- *difference in size*: If same objects are shown at different sizes, the larger object seems to be closer than the smaller one. This criterion is basically a consequence of the perspective depth cue.
- *known dimensions of objects*: Known sizes of objects are also influencing the subjective depth perception.
- *shading*: Occluding and covering enables a perception of relative position of several objects with regards to each other. The object shown with a closed shape is perceived as closer than the other.
- *light and shadow*: The shadow within an object makes conclusions about its spatial structure possible. Position and size of the outer shadow gives information about the kind of object (mountain or valley) and its size.
- *accommodation*: Examining and focussing an object requires an adjustment of the refraction of the optical lens to get a sharp picture on the retina. This is called accommodation.

The binocular depth cues require the total binocular eye system. They influence the perception of short to medium distances.

Traditional binocular depth cues are:

- *convergence*: For examining and fixation of a point with both eyes the eyeballs have to be counterrotated, until both lines of sight meet at the fixated point. Only if this happens the object is pictured at identical points of both retinas and a further processing of the stimulus is possible.
- *disparity and parallax*: If one object is focussed in space, other objects are represented at non-corresponding retina areas, causing two different pictures for the right and left eye. The disparity is defined as the distance between both single pictures. Because of the importance for the Electronic Sandtable, this depth cue will be described in detail in chapter 6.3.

Additionally to these static cues further dynamic cues exist which have large influences on the depth perception for medium distances (17–29 m) (Kelle, 1994). Because they are of no relevance for the semi-immersive display technology, they will not be described in this paper.

### 6.3 Disparity and Parallax

Disparity and parallax have a large influence on depth perception and are the main depth cues for stereoscopic visualisation. Therefore they are described more detailed.

The distance between both eyes leads to different representations of an object on the retina of the right and the left eye. Both eyes perceive the object with a

different perspective. The distance between both pictures is described by disparity.

If an object is looked at, it is represented at the fovea of both eyes. A round spatial surface exists (horopter), representing all objects on it on corresponding retina aerials. Objects at positions different from the horopter are represented at non-corresponding retina areas. If the distance from the horopter is not too large, the cerebrum fusions the right and left picture to a three dimensional model. If it is too large, disturbing double pictures are perceived (Schmidt & Thews, 1995).

Disparity is a mathematical dimension and cannot be determined practically. Therefore the dimension of the *stereoscopic parallax* has been introduced. For this a reference level has been used which is parallel to the eyes' level and runs through the fixation point.

Parallax has been defined as (Helmholtz, 1910, ref. in: Kelle, 1994):

$$p = b_a \times a \times \frac{t}{e^* t + e^2}$$

$p$  = parallax

$b_a$  = inter ocular distance

$a$  = distance eyes / reference level

$e$  = distance reference level / object

$t$  = distance eyes / object ( $=a+e$ )

Parallax is also a dimension for depth separation and depth perception. Therefore it is deduced that depth perception decreases with square distance. Furthermore it increases linearly with inter ocular distance.

According to Kelle (1994), stereoscopic disparity and parallax has been found to be useful only for near and medium distance (maximum of 6–9 m).

Visualisation of geographic data of large scale means a large distance between eye point and surface. It can be concluded that exact modelling means that parallax and stereoscopic depth perception will be very low. Consequently, an exclusive use of real values for the model parameters (e.g. depth scale) would lead to no stereoscopic depth perception and the scene would be perceived flatly. On the other hand, too large values e.g. for depth scale would make the terrain more mountainous and may cause a wrong mental model of the terrain. For an ideal depth perception these parameters have to be adapted so that operators perceive the terrain structure subjectively correctly. Therefore a dynamic adaptation of the interocular distance of operators and depth scaling is needed.

Pilot experiments for determining optimum inter-ocular distance and depth scale have just started.

#### 6.4 Stereoscopic Projection

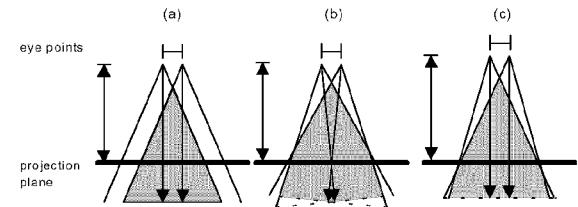
For three-dimensional stereoscopic visualisation three different projection models are commonly used. Their baseline geometry is illustrated in Figure 6.

In Computer Aided Design (CAD), aerial photo analysis and for head-mounted-displays (HMD) *projection models with parallel line of sights* are used, as shown in Figure 6 (a). They are based on the assumption of a centre eye-point perpendicular to the projection plane.

Right and left projections are calculated by using offset values and parallel shifting the projection right and left. The disadvantage of this model is that the scene can only be visualised underneath the projection plane. This is inconvenient for the concept of the Electronic Sandtable, because the scene would always be located beyond hand range. Another disadvantage is clipping at the borders of the display as missing visual information for either right or left eye appears. Especially at large displays this is very irritating for operators.

Figure 6 (b) shows the geometry of a *projection model using rotated line-of-sights*. Here the projections are rotated in the way that both lines-of-sight meet in the projection plane. The lines-of-sight do not stay perpendicular to the projection plane. It enables a visualisation underneath and as well as above the projection plane. There are no irritating effects on the borders of the display either. But because of the special geometry, an error of vertical parallax occurs. It can be observed at the borders of the display, where both lines meet at a point, which is above the projection plane. This leads to a “winding”-effect and the scene seems to be projected on a cylinder rather than a plane. Vertical parallax has found to be irritating especially on large displays.

The last projection model uses *window projection*, which means that two windows are introduced through which the virtual scene is perceived. The windows are positioned in the same level as the projection plane. Both lines-of-sight meet at the projection plane and remain perpendicular to it. In this model, stereoscopic parallax is only dependent on the distance to the display and no vertical parallax is introduced.

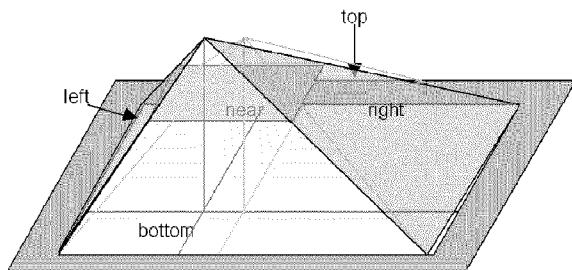


**Figure 6:** 3 projection models: (a) parallel projection, (b) rotated projection, (c) window projection

This model is used for the Electronic Sandtable. As shown in Figure 7, an asymmetric pyramid describes the model for each eye. This means, the perpendicular line through the top does not meet the centre of the pyramid basis.

For each projection six parameters are used to identify the pyramid. They include the values for front, back, top, bottom, left and right clipping plane. These values are calculated by x,y,z-position of both eye-points, scale factor and the display size as input.

Pilot experiments have shown good results for this projection model. Only little perspective error due to tracking of real eye position was determined. In future, this error will be minimised by calibrating the tracking equipment.



**Figure 7:** Right and left asymmetric projection pyramid and boundary surfaces (clipping planes)

## 7. Conclusion and Future Research

In this paper the baseline concept of using semi-immersive VE-technology as advanced TSD has been described. The approach has been shown to be promising and advantageous.

It has been emphasised that human factors and ergonomics are the main issues for reasonable VE-application. In this paper some research issues were introduced and results of ongoing research studies in the area of visualisation were presented.

So far only real-size shapes have been visualised. In future geographic data of different scales will be used. To evoke a stereoscopic depth perception, an adaptation of the scale factor for elevation as well as the dimension of inter ocular distance is necessary.

Another research topic is the maximum vertical range of the display. The display technique causes contradicting depth information, because both eyes accommodate on the projection plane, but fixate an object closer or more far away. However, if the virtual scene is too close, parallax becomes too large and the cerebrum cannot fusion both pictures. Therefore another research topic will be to determine the maximum useful vertical display range and the variability of human sense perceiving.

Pilot experiments in the visualisation area have been started and are currently going on.

Other important areas with high influence on the applicability of VE in C<sup>2</sup> are interaction and co-operation.

Interaction with the databank means navigation in the scene and manipulation of virtual objects. Procedures (software) and interaction devices (hardware) have to be designed, evaluated and analysed according to the application for both subgroups.

The concept of the Electronic Sandtable has been designed to enable multiple operators working in the virtual scene. It has to include co-operation concepts. In contrast to full-immersive VE, in semi-immersive VE all operators are present at the same location. Communication and inter-operator interaction work the natural way. Therefore mainly human-computer interaction issues have to be analysed. These main issues and problems are the development of a general concept for co-operation and co-operation procedures.

But even if in future the system works as it is supposed to be, one question to be answered still remains: The question for quantification of the profit and gain of using

VE-systems. The key criteria for answering this question will be performance of the human-VE system.

For this reason human performance metrics will have to be introduced, formulated and analysed. They should be as fundamental as possible, but still take into account the characteristics of the application.

Jointly with other basic research studies they will be the key issues of future research in this area.

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